From the Western Vascular Society

Reassessing the normal toe-brachial index in young healthy adults

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Objective: **The purpose of this study was to measure the toe-brachial index (TBI) in healthy young adults and to compare it with the accepted reference range.**

Methods: **Medical students from the undergraduate classes at the University of British Columbia were prospectively recruited. Participants were surveyed on physical parameters (height, weight), lifestyle factors (physical activity and type, smoking status, alcohol consumption), and medical history (current medications, medical conditions, family history). Bilateral brachial, ankle (using both dorsalis pedis and posterior tibial arteries), and toe blood pressures were measured by stethoscope, Doppler device, and photoplethysmograph, respectively. Ankle-brachial index (ABI) and TBI were calculated and assessed against published reference ranges. TBI was calculated as the mean great toe blood pressure divided by the average of the higher arm systolic blood pressures.**

Results: **Seventy-three medical students with a mean age of 24.3 ± 2.0 years without any comorbidity were studied. Participants maintained relatively healthy lifestyles (hours of activity per week, 4.6 ± 2.7; body mass index, 21.9 ± 2.4). Caffeine and alcohol consumption was modest (8.2 ± 8.0 and 1.7 ± 2.6 servings/week, respectively). There were no current or past smokers. No significant differences in lifestyle factors were observed between men and women. Mean brachial blood pressure was 116 ± 10 mm Hg (left) and 120 ± 11 mm Hg (right). Mean TBI was 0.98 ± 0.12 (left) and 0.97 ± 0.12 (right) for men and 0.95 ± 0.21 (left) and 0.94 ± 0.21 (right) for women. The overall ABI was 1.10 ± 0.07 when averaged by gender and side. Whereas men had significantly higher blood pressures in the arm, toe, and ankle compared with women, these differences disappeared when the indices were determined. There were no significant differences in TBI or ABI between men and women.**

Conclusions: **In comparison to published reference values, the TBI in young, healthy individuals is significantly higher. Whereas no gender difference existed, greater variability of the TBI was observed in women. Further studies are recommended to determine if the threshold for diagnosis of peripheral arterial disease based on TBI should be raised. (J Vasc Surg 2016;63:652-6.)**

Peripheral arterial disease (PAD) is an atherosclerotic occlusive disease of the lower extremities and is common, considering that it frequently coexists with coronary artery disease, diabetes, hypertension, and other chronic diseases. It regularly is manifested with claudication and in the more advanced stages can lead to critical limb ischemia. A few diagnostic methods may be used to diagnose PAD, including pulse volume recordings and arteriography, but the most commonly employed is the ankle-brachial index (ABI).

The ABI, the ratio of ankle to brachial systolic blood pressures, is a simple, objective, and noninvasive method to diagnose and to observe PAD.[1] A resting ABI of ≤0.90 is the accepted definition of PAD.[2] However, medial sclerosis of the arteries in the ankle, which is common in conditions including diabetes, chronic kidney disease, and advanced age,[3-6] can interfere with the ABI and affect the validity of this measurement.[7] This inaccuracy arises as calcified vessels in the ankle are frequently stiff and resistant to compression, thereby causing false elevations of the ABI. The arteries in the toes, however, are less susceptible to calcification even when comorbidities are present.[8,9] Thus, the toe-brachial index (TBI), calculated as the ratio of toe to brachial systolic blood pressure, can be used to examine for PAD in patients with medial sclerosis.[9,10] Toe pressures are believed to be 20 to 30 mm Hg less than ankle pressures, and a TBI <0.70 is indicative of PAD, although the range may be as much as 0.60 ± 0.20.[2,11] In our laboratory, we use a TBI threshold of <0.6 as diagnostic of PAD.

Clinically, we have encountered patients who present with findings of PAD based on history (leg claudication, cool extremities, nonhealing wounds, decreased leg hair

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growth) or lack of peripheral pulses or who have incompressible tibial arteries that give spuriously high ABIs, yet they have TBI values >0.6. These patients are considered not to have PAD, although clinical suspicion usually leads to imaging studies that ultimately lead to the diagnosis of PAD.

The basis for diagnosis of PAD by this TBI cutoff level of 0.6 or 0.7 is not well referenced. More recently, Hoyer et al[12] reviewed the results of eight small studies (N = 287) and suggested that average TBI in normal patients with ages ranging between 21 and 75 years was 0.87. Having a lower TBI threshold to diagnose PAD is valuable in confirming with confidence patients who have severe PAD but at the same time may potentially underdiagnose patients at an earlier, asymptomatic stage where counseling may be beneficial.

Given the apparent discrepancy between the recognized TBI level to diagnose PAD and this recent report, we sought to determine TBI levels in the normal population who would not be expected to have PAD. Once this information had been obtained, it could serve as the basis for future studies. For this study, we specifically wanted to determine the TBI in a young, healthy population and to compare the result with the currently accepted clinical value.

METHODS

Participant recruitment and inclusion and exclusion criteria. Medical students from the first- and second-year classes at the University of British Columbia were prospectively recruited by e-mail and personal communications. The recruiting period was from February to May 2014. After providing their consent for participation in the study, all participants completed a written health and demographic questionnaire detailing their physical measurements (height, weight, hand dominance), lifestyle factors (level of physical activity, perceived stress level, smoking status, alcohol and caffeine consumption), and medical history (current medications, chronic conditions, family history). No students were excluded from this study.

Data collection: blood pressure measurements. Measurements were all performed in the same room, and the room temperature was held relatively constant between 20.1°C and 21.8°C. All participants rested supine for a minimum of 5 minutes before any measurements were taken and remained supine for the entirety of the examination.

Brachial blood pressure was measured by auscultation in accordance with The Canadian Hypertension Education Program 2013 recommendations protocol. The left and right brachial blood pressures were each measured twice, with a third taken if the two values differed by more than 6 mm Hg. The participant was allowed to rest for at least 1 minute between each measurement. The closer of the two values was averaged for the TBI calculations.

Ankle systolic blood pressure was determined by a hand-held Doppler device (LifeDop 150; Summit Doppler, Wallach Surgical Devices, Turnbull, Conn), with a standard blood pressure cuff positioned immediately proximal to the malleoli. Both dorsalis pedis (DP) and posterior tibial (PT) arteries were used for pressure determination. After location of the DP and PT arteries by palpation, standard ultrasound gel was applied to the skin, and the artery signal was again confirmed by Doppler examination. The blood pressure cuff was then inflated to approximately 20 mm Hg above the point at which the artery signal was ablated, and the cuff was then slowly released at a constant rate (approximately 2 mm Hg per second) until the artery signal reappeared. Both sides were repeated in duplicate, with the maximum allowable difference being 6 mm Hg. When repeated measurements were taken, the closer of the two values was averaged for the ABI calculations.

Toe systolic blood pressures were measured by photoplethysmography (PPG). The photoplethysmograph (MD6RP; D. E. Hokanson Ltd, Bellevue, Wash) was attached to a continuous chart recorder and an aneroid sphygmomanometer with an appropriately sized digit cuff (Hokanson Ltd) on the hallux. With the patient supine, the PPG phototransducer was affixed on the plantar surface of the hallux with Velcro while ensuring that the entire sensor surface was in contact with the participant's skin. The digit cuff was then affixed proximal to the PPG phototransducer with adequate separation between the two cuffs to prevent signal noise. Either a 1.9 × 9-cm or 2.5 × 9-cm cuff was used and chosen such that the cuff would not contact the PPG sensor when both were attached to the hallux, and when inflated, the bladder would completely occlude the PPG signal. Proper positioning of the apparatus was then evaluated by assessing the capture from PPG to ensure that a clear phasic signal of the basal toe blood flow was detected. The digit cuff was then inflated to approximately 30 mm Hg above the point at which the phasic signal was obliterated. Subsequently, the cuff was deflated at a consistent rate of approximately 2 mm Hg per second until the reappearance of a continuous phasic signal was noted. The pressure at which the first waveform appeared was taken as the systolic toe blood pressure. Both left and right halluces were measured in duplicate, and if the duplicate from one side was >6 mm Hg apart, a third measurement was taken for that side. The participant was allowed to rest between each measurement. The closer of the two values was averaged for the TBI calculations.

The ABI was determined using either the DP or PT artery; thus, two different values were obtained for the ABI. The ABI was the averaged systolic blood pressure of the subject artery divided by the higher of the averaged brachial systolic blood pressures. The TBI was calculated by dividing the averaged toe systolic blood pressure by the higher of the averaged brachial systolic blood pressures.

Statistical analysis. Statistical analysis was performed with GraphPad Prism (version 6.0d; GraphPad Software, Inc, La Jolla, Calif) and Microsoft Excel (version 14.1.0; Microsoft Corp, Mississauga, Ontario). Measurements are presented as mean with standard deviation or as the 95% confidence interval where the reference range was calculated. Differences in mean values were determined by Student *t*-test, with statistical significance defined as $P < .05$.

Research ethics. This study was approved by the University of British Columbia Clinical Research Ethics Board (H13-03144).